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A computerised data handling procedure for defect detection and analysis for large area substrates manufactured by roll-to-roll process

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Abstract

The development of optical on-line/in-process surface inspection and characterisation systems for flexible roll to roll (R2R) thin film barriers used for photo-voltaic (PV) modules is a core research goal for the EU funded NanoMend project. Micro and nano scale defects in the ALD (atomic layer deposition) Al_2O_3 barrier coating produced by R2R techniques can affect the PV module efficiency and lifespan. The presence of defects has been shown to have a clear correlation with the water-vapour-transmission-rate (WVTR). Hence, in order to improve the PV cell performance and lifespan the barrier film layer must prevent water vapour ingress. One of the main challenges for the application of in process metrology is how to assess large and multiple measurement data sets obtained from an in process optical instrument. Measuring the surface topography over large area substrates (approximately 500 mm substrate width) with a limited field-of-view (FOV) of the optical instrument will produce hundreds/thousands of measurement files. Assessing each file individually to find and analyse defects manually is time consuming and impractical. This paper reports the basis of a computerised solution to assess these files by monitoring and extracting areal surface topography parameters. Comparing parameter values to an experimentally determined threshold value, obtained from extensive lab-based measurement of Al_2O_3 ALD coated films, can indicate the existence of the defects within a given FOV. This process can be repeated automatically for chosen parameters and the existence of defects can be indicated for the entire set of measurement files spontaneously without interaction from the inspector. A running defect log and defect statistics associated with the captured set of data files can be generated. This paper outlines the implementation of the auto-defect logging using advanced areal parameters, and its application in a proof of concept system at the Centre for Process Innovation (UK) is discussed.

1 Introduction

Thin-film flexible solar modules technology is currently being extensively researched as a cheap energy source when compared to more expensive rigid Si-based solar modules. Emerging photovoltaic (PV) technology, such as copper indium gallium selenide (CIGS) cells, has effectively increased the efficiency of the flexible modules and these are now commercially competitive with other flexible solar cell technologies. Research has shown that the main disadvantage of this technology is that the modules are highly susceptible to long-term environmental degradation due to the water vapor ingress [1]. A specific solution has been introduced to deposit a high quality single layer of Al_2O_3 on a polymer using atomic layer deposition (ALD) method. However, the presence of defects on the film surface during the deposition growth of the Al_2O_3 are found to be highly detrimental to the PV module efficiency and lifespan. Consequently, an on-line inspection defect detection system would be an optimal solution for improvement of production quality. As part of the EU NanoMend project, the authors have reported an optical technique based on wavelength scanning interferometer (WSI). The on-line sensor is capable of high resolution defect measurement and combined with kinematic translation and auto-focus stages to provide a full measurement coverage of the substrate as described in the proof-of-concept system shown in Figure 1 [2].

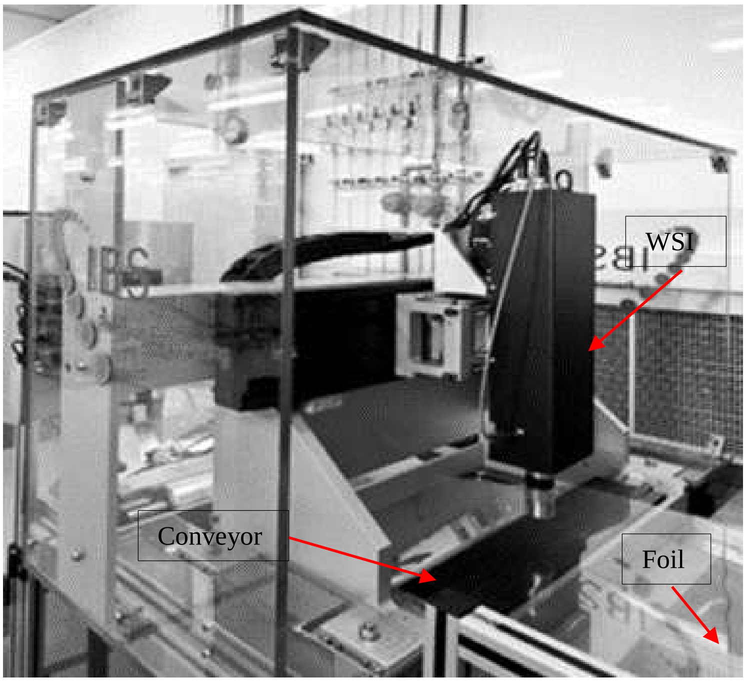


Figure 1: On-line inspection system integrated into rewinder stand

2 Defect measurement and characterisation

It has been shown that there is a clear correlation between the significant defects density and the water vapour transmission rate (WVTR) [3] for Al_2O_3 barrier films. In addition there is excellent correlation with lab based offline metrology systems (CCI 3000) and the WSI instrument used in this paper. Two exemplar substrates of Al_2O_3 ALD barrier film tested for WVTR at NPL were inspected using the WSI and a commercial CCI 3000. The surface topography of 12.5% of the total area (equivalent to 9 cm^2) has been measured and more than 100 measurement files containing defects were obtained for each sample. The criteria used to segment the defects were based on defects lateral size of ≥ 3 µm and 3Sq vertical dimension. These levels were established by a previous study [4]. The measurement results shown in Figure 2 demonstrate a clear correlation between the defects density and the measured WVTR. The sample with high WVTR ($3.4x10^{-4}g/m^2/day$) is seen to have higher density of significant defects than the sample with low WVTR ($1.3x10^{-4}g/m^2/day$). The analysis shows the capability of WSI to distinguish significant defects (lateral dimension >3 µm and vertical height > 3Sq) as compared to a commercial CCI 3000 (Taylor Hobson).

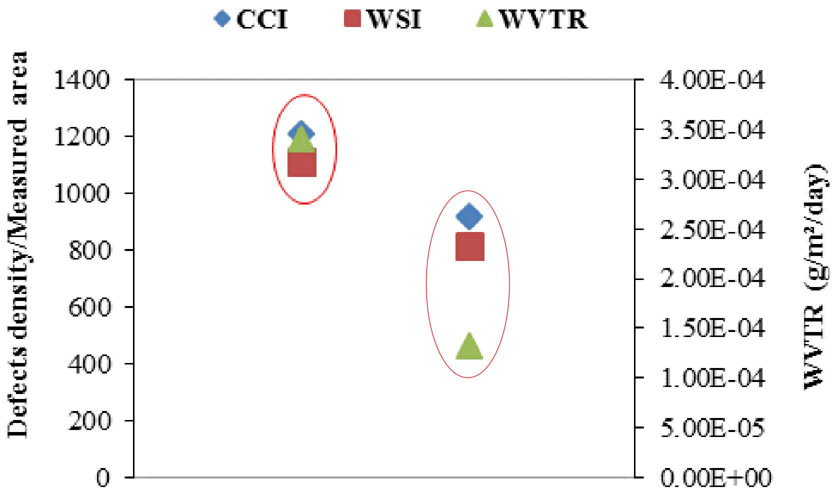


Figure 2: Defects density versus WVTR for two samples

The study also found that the RMS surface roughness for defect free samples measured by the WSI was (Sq=6.7 nm). This value is significantly higher when compared to the CCI method (Sq=0.8 nm). This is may be attributed to the high noise floor level generated during the operation process of the WSI technique. The noise is thought to be generated from accumulative effects of environmental noise, WSI resolution and measurement uncertainty. However, this noise level does not affect the ability of the system detect or characterise defects since the vertical magnitude of the functionally significant defects is considerably higher than the noise level.

3 Computerised Method for data handling

One of the main challenges for in process metrology applications such as reported here is how to assess the large and multiple measurement data sets. Many measurement files (typically 1000 measurement files per substrate width with overall data size larger than 300 M byte) will be produced over large area substrates (approximately 500 mm width) with a limited field-of-view (FOV = 0.5mm x0.7 mm for 5x objective lens). Therefore, a computerised solution to assess these files by monitoring surface topography parameters was developed as illustrated in Figure 3. Significant defects have a direct impact on the global surface roughness of the measured data set. Consequently the Sq parameter is chosen as a monitoring function to distinguish between data sets with significant and non-significant/free defects. Based on the above logic, a threshold limit was set to 3×Sq of a defect free Al_2O_3 sample. 3Sq is chosen as it represents 3 × standard deviation roughness and any data set above this could reasonably be considered as containing defects. The Sq value has been determined experimentally by measuring defect free samples using the WSI; as such the average Sq is determined to be approximately equal to 7 nm. The threshold limit for this procedure (3×Sq = 21 nm) is employed as a statement condition in the proposed computerised model, see Figure 3.

So if the Sq of the measured surface is greater than the threshold limit, the surface will be subject to data segmentation procedure to extract the significant defects. Otherwise, the measurement will be treated as defect free surface. For data segmentation, the edge processing using Wolf and area-pruning methods are employed to identify and characterise the defects.

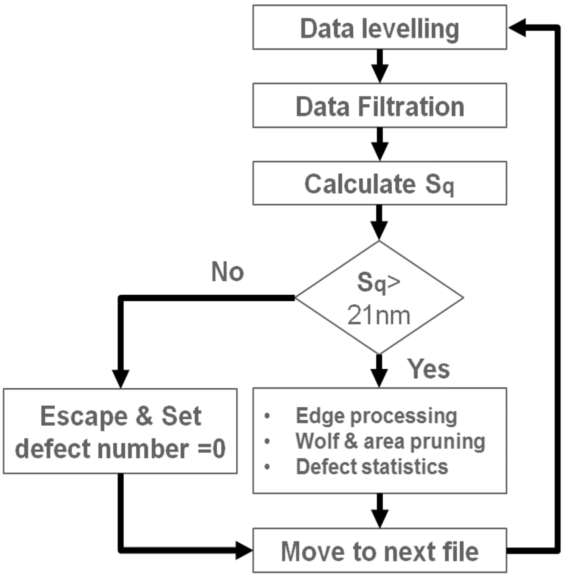


Figure 3: Flow-chart of the computerised data handling method for WSI

The Wolf pruning method, as defined in ISO 25178-2 [5], allows the detection of significant features on the barrier surfaces and the determination of their morphology parameters (dimension, area, volume etc.). The protocol used for characterising the barrier films used in this study is described in the flow chart, where firstly, the surface was filtered to eliminate data noise, this is achieved using box filtering (Gaussian filtering) with a cut-off of 2^n points; where n is the smooth level (from 1 to 5), and n was specified to be 5. After the smoothing process, edge processing was performed on the data using a Sobel type operator [5]. The edge data is then "pruned" by means of Wolf pruning [6] where all data elements below 10% of the Sz (of the edge filtered surface) value are deemed insignificant, and those elements higher than 10% Sz (of the edge filtered surface) were retained as significant. Following Wolf pruning an area prune was applied where if an area was found to be ≤ 3 um lateral diameter (this area is calculated based on a mathematical model published by [4] it was deemed insignificant. Figure 4 shows an exemplar defect measured by the WSI, and Figure 5 shows the segmentation process and the power of the procedure for extracting defects from the surface data.

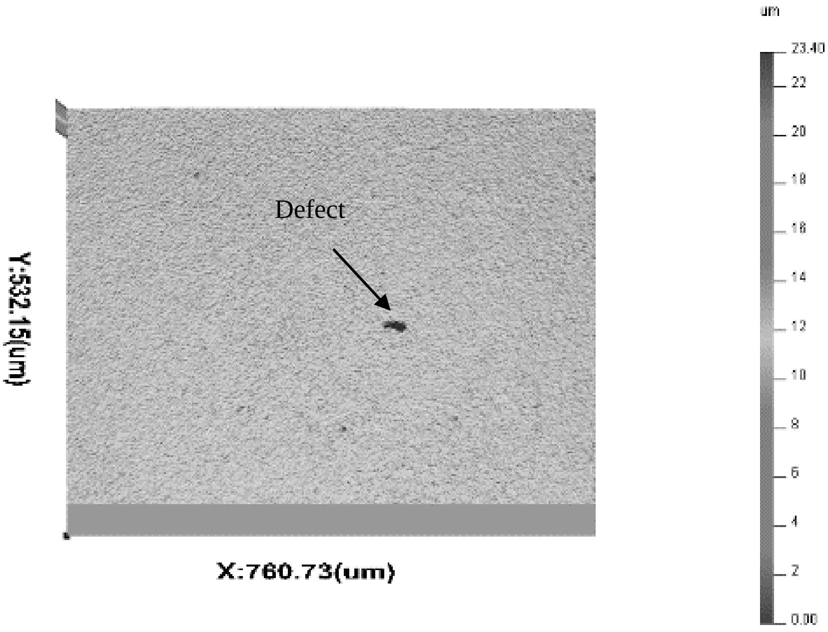
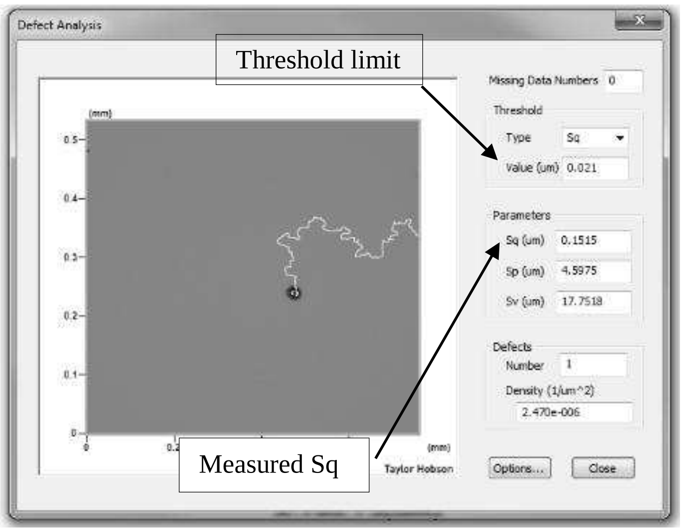


Figure 4: Hole type defect measured by the WSI



Threshold limit

Measured Sq

Missing Data Numbers: 0

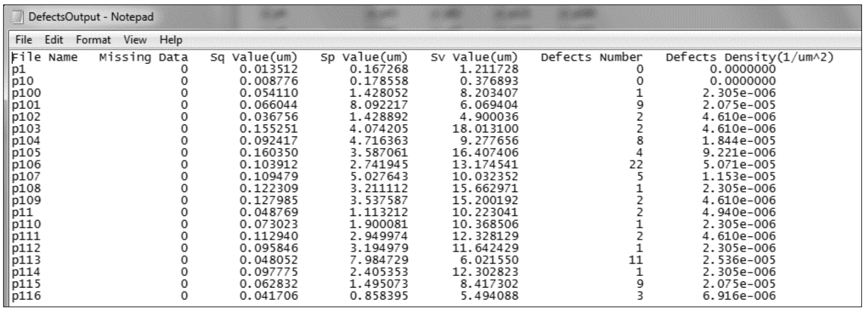
Threshold
Type: Sq
Value (um): 0.021

Parameters
Sq (um): 0.1515
Sp (um): 4.5975
Sv (um): 17.7518

Defects
Number: 1
Density (1/um^2): 2.470e-006

Figure 5: Defect extraction using data segmentation (edge processing and wolf pruning)

The procedure can be repeated to analyse the entire measured files to extract and count defects and determine a chosen surface parameters (Sq, Sp and Sv) as given in the output text file shown in Figure 6.



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File Name   Missing Data   Sq Value(um)   Sp Value(um)   Sv Value(um)   Defects Number   Defects Density(1/um^2)
p1                     0       0.013512       0.167268       1.211728                0         0.0000000
p10                    0       0.008776       0.178558       0.376893                0         0.0000000
p100                   0       0.054110       1.428052       8.203407                1         2.305e-006
p101                   0       0.066044       8.092217       6.069404                9         2.075e-005
p102                   0       0.036756       1.428892       4.900036                2         4.610e-006
p103                   0       0.155251       4.074205      18.013100                2         4.610e-006
p104                   0       0.092417       4.716363       9.277656                8         1.844e-005
p105                   0       0.160350       3.587061      16.407406                4         9.221e-006
p106                   0       0.103912       2.741945      13.174541               22         5.071e-005
p107                   0       0.109479       5.027643      10.032352                5         1.153e-005
p108                   0       0.122309       3.211112      15.662971                1         2.305e-006
p109                   0       0.127985       3.537587      15.200192                2         4.610e-006
p11                    0       0.048769       1.113212      10.223041                2         4.940e-006
p110                   0       0.073023       1.900081      10.368506                1         2.305e-006
p111                   0       0.112940       2.949974      12.328129                2         4.610e-006
p112                   0       0.095846       3.194979      11.642429                1         2.305e-006
p113                   0       0.048052       7.984729       6.021550               11         2.536e-005
p114                   0       0.097775       2.405353      12.302823                1         2.305e-006
p115                   0       0.062832       1.495073       8.417302                9         2.075e-005
p116                   0       0.041706       0.858395       5.494088                3         6.916e-006
```

Figure 6: Defect extraction output of the computerised method

4 Conclusion

The segmentation analysis can effectively distinguish significant defects from non-significant defects using Wolf and area pruning methods. Prior to segmentation process, the 3×Sq value of the surface can be used as a threshold limit to monitor surfaces for indicating the existence of significant defects. The computerised method described in this paper (based on data segmentation protocol) is seen to be practical and powerful tool to analyse large and multiple data sets and count for defects with lateral dimension > 3 um. This model can be used for on-line inspection system for roll-to-roll manufacturing process without the need for interaction from the inspector.

3 Acknowledgement

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